

# Relativistic Emission Lines and Ionized Outflow in NGC 4051 Measured with XMM

Patrick Ogle      UCSB

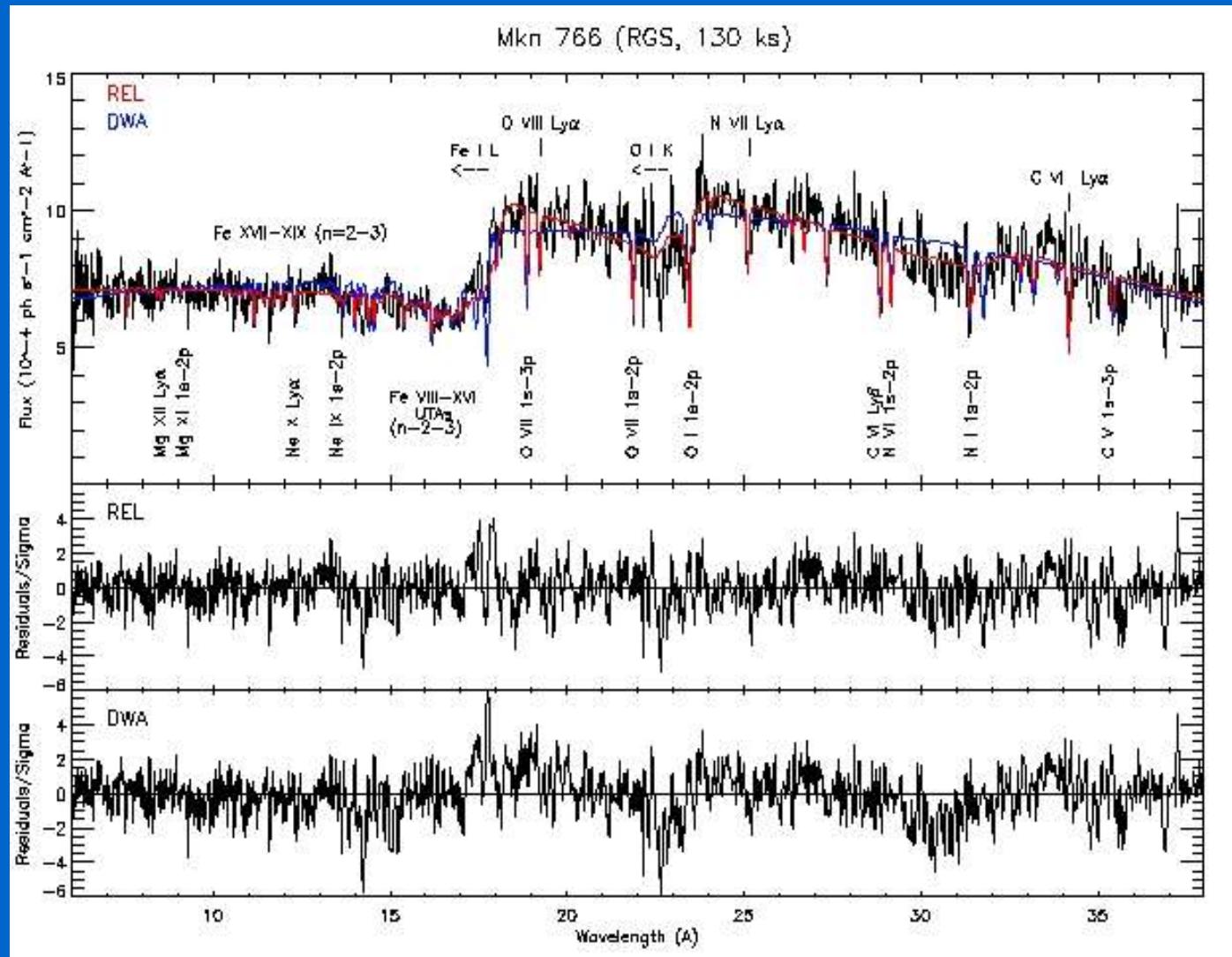
K. O. Mason, M. J. Page, N. J. Salvi      MSSL

F. A. Cordova, I. M. McHardy, W.C. Priedhorsky

# Overview

- ★ Emission lines from the inner accretion disk:  
Mkn 766  
NGC 4051
- ★ NGC 4051 outflow: kinematics, ionization.
- ★ NGC 4051 variability, low vs. high-state spectra.

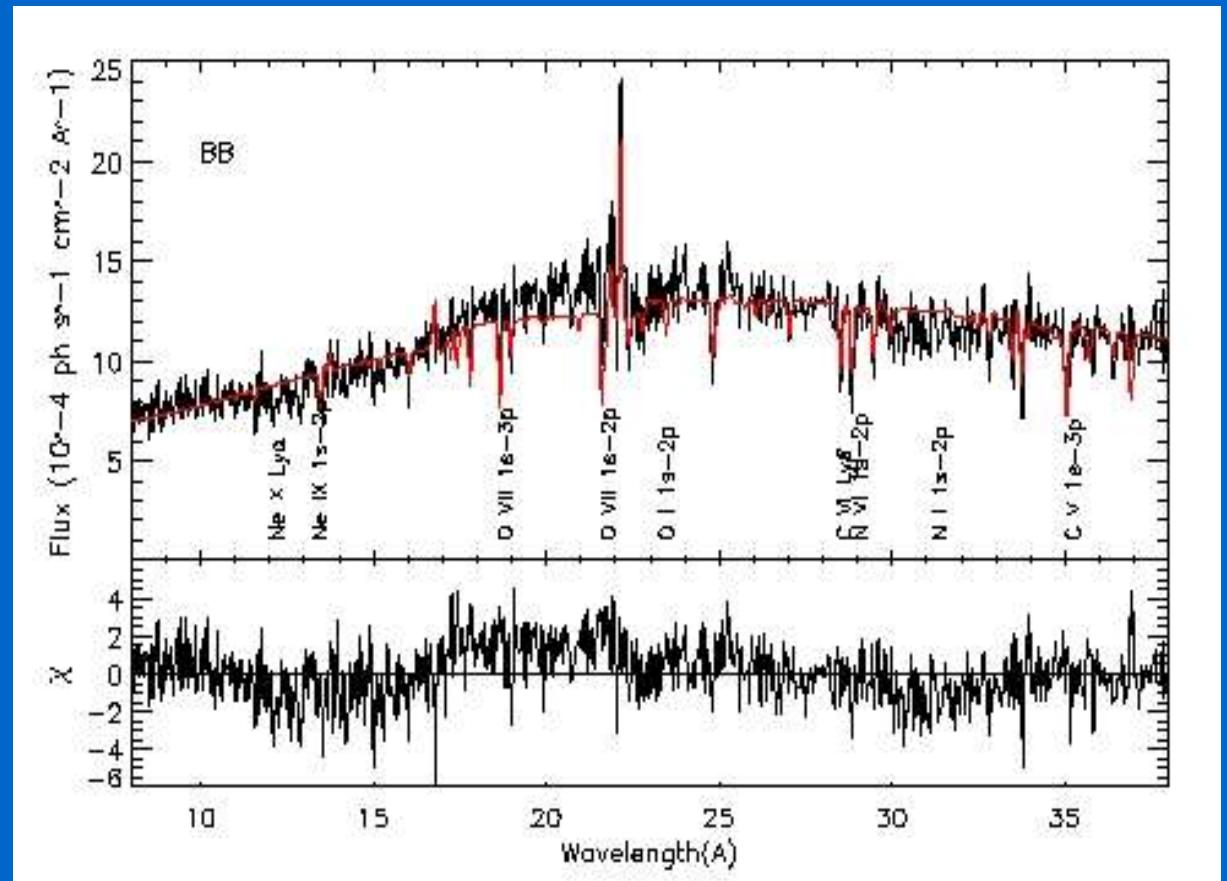
# Relativistic Lines in Mkn 766



Mason et al., Sako et al. 2003, Branduardi-Raymont et al., Lee et al. 2001

# NGC 4051 Soft X-ray Excess

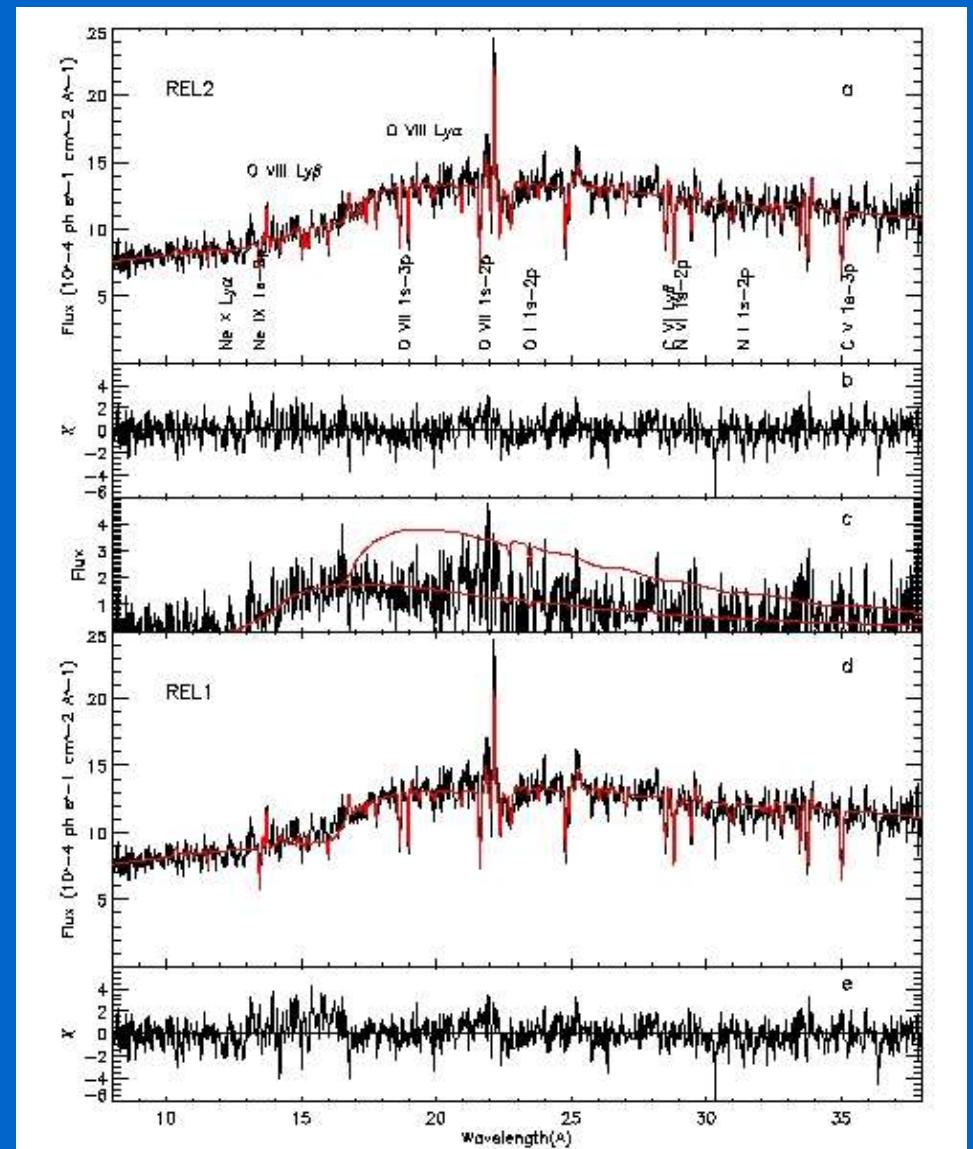
- RGS, 100 ks
- PL:  $\Gamma = 2.35$
- BB:  $kT = 0.13$  keV
- Fit  $\chi^2/\text{DF} = 2.39$  is very poor!
- ★ Broad bump and no obvious PI edges.



Ogle et al. 2003, Collinge et al. 2001, Guanazzi et al. 1998

# Relativistic O VIII in NGC 4051

- Rel. line fits
- a: O VIII series
- b: residuals
- c: Ly $\beta$  + higher order lines
- d: O VIII Ly $\alpha$  only
- e: residuals

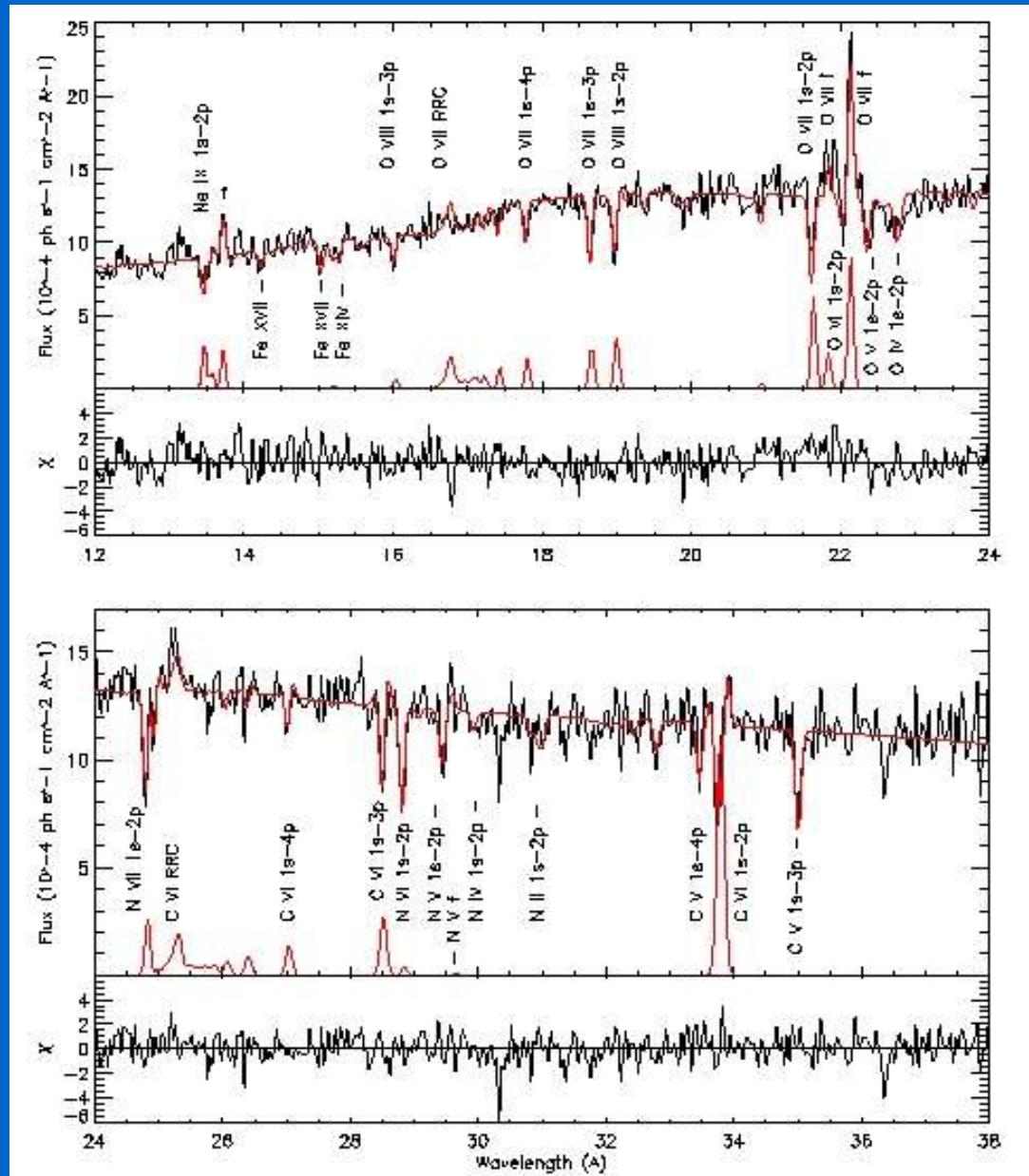


# RLR parameters

- Best fits O VIII Laor/series:  $\chi^2/\text{DF} = 1.65, 1.38$
- Radii:  $R_i = 1.24 R_G$ , fixed ( $R_G = GM/c^2$ )  
 $R_o = 400 R_G$ , fixed
- Line Emissivity  $\sim R^q$  ( $q = -5.24 \pm 0.07$ )  
(Half-light radius =  $1.53 R_G$ )
- Inclination:  $i = 47.1 \pm 0.5$ , matches [O III] cone  
(Christopoulou et al. 1997)
- $M_{\text{BH}} = 1.5 \times 10^6 M_{\text{sun}}$  ( $M_{\text{BH}} \sin i$ : Peterson et al. 2000)
- N VII/O VIII < 0.09, C VI, O VIII < 0.14
- Fe XXV:  $R_i = 1.56 R_G$ ,  $q = 6.2$ ,  $i = 57 \pm 10$ ,  $\text{EW} = 70 \text{ eV}$

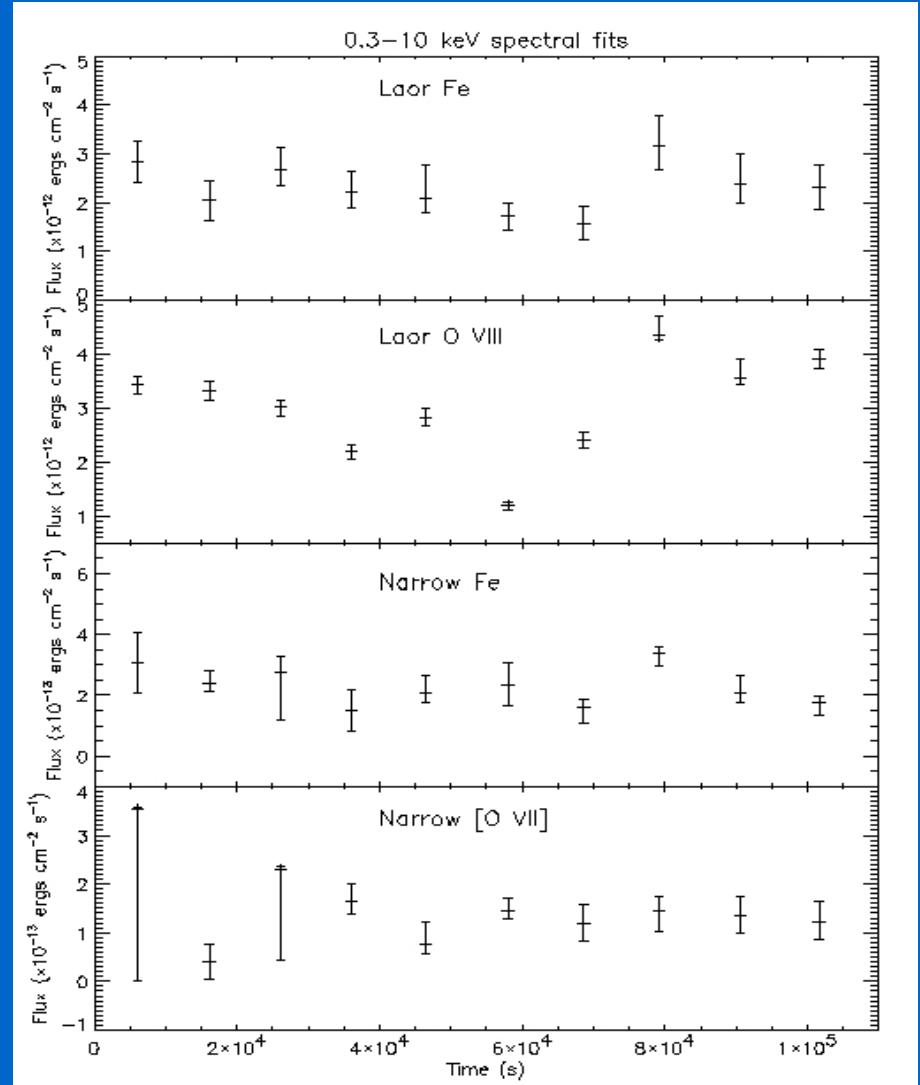
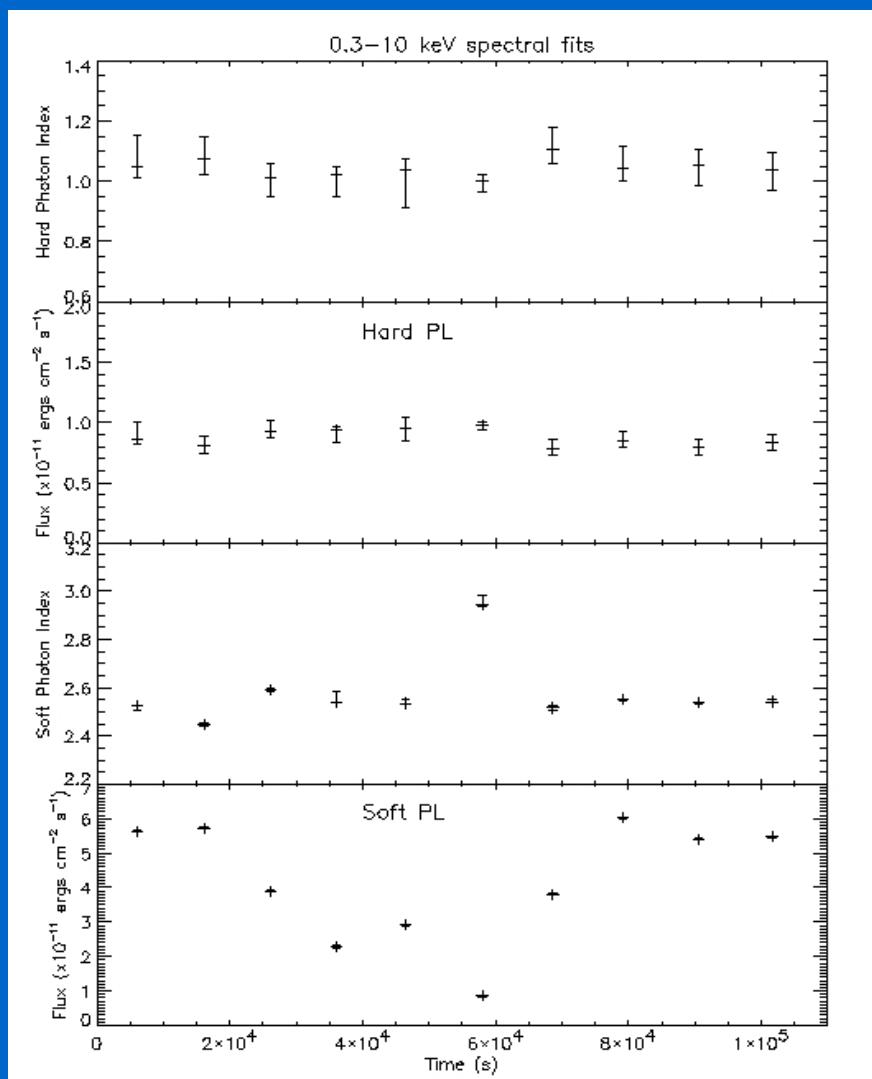
# NGC 4051 ionized absorber/emitter

- ★ Absn series from:  
K-shell C, N, O, Ne,  
inner-shell N, O  
L-shell Fe.
  - $V_a = -670 \pm 150$  km/s,  
 $b = 192 \pm 8$  km/s
  - ★ Re-emission partially fills  
absn lines. ( $f_c = 77\%$ )
  - O VII, Ne IX i, f,
  - $V_e = -160 \pm 90$  km/s
  - ★ Broad C VI Ly $\alpha$ , RRC  
 $b = 700$  kms  $\pm 30$  km/s



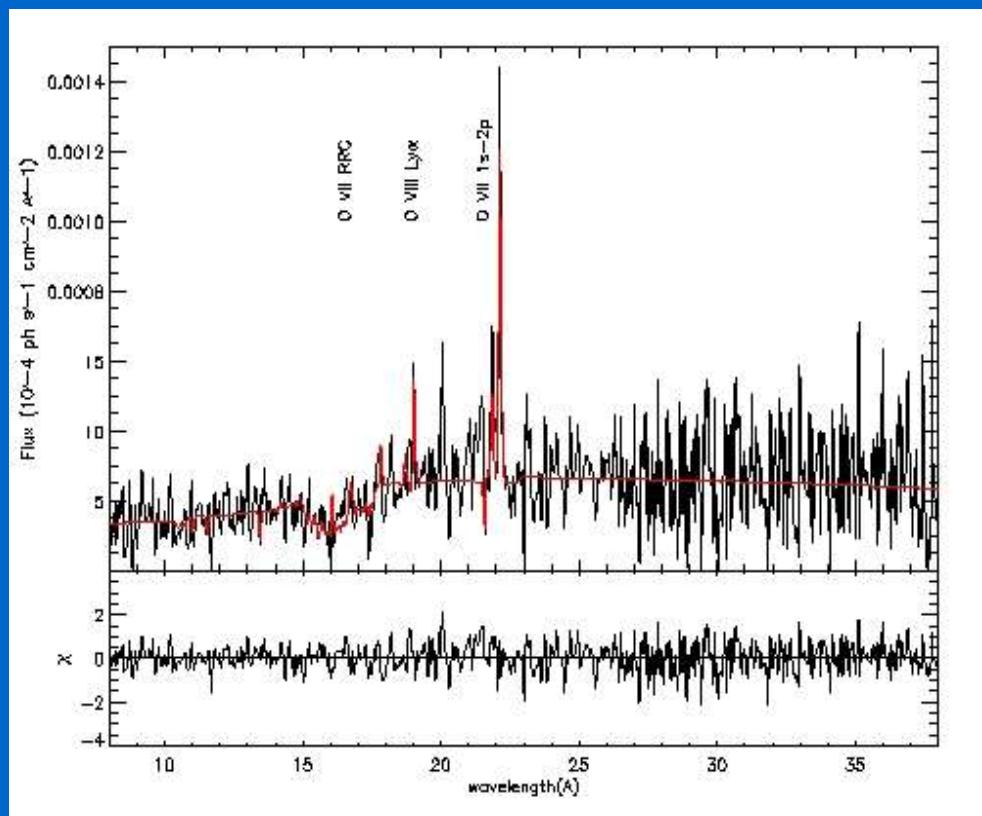
# Epic spectral variability

Salvi et al. 2003, same epoch as RGS



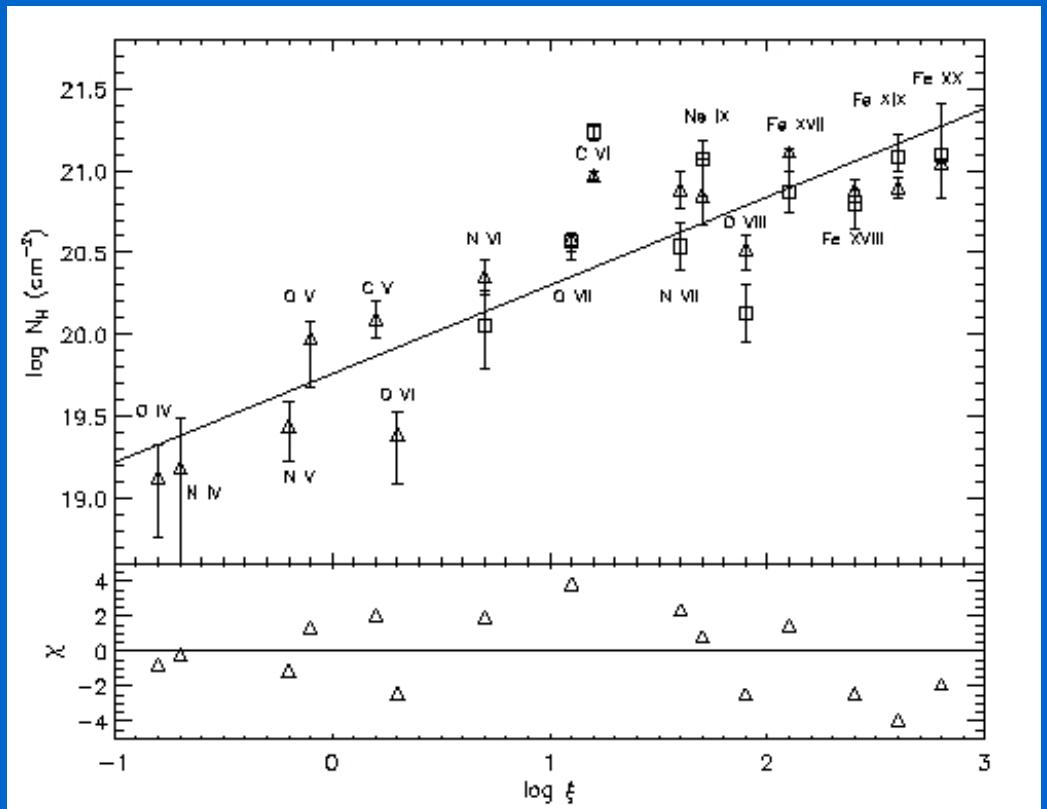
# NGC 4051 low-state RGS spectrum

- ★ Rel. O VIII still there!
- High EW O VII, O VIII narrow lines.
- Absorber parameters not well constrained, but consistent with high state.
- Possible UTA



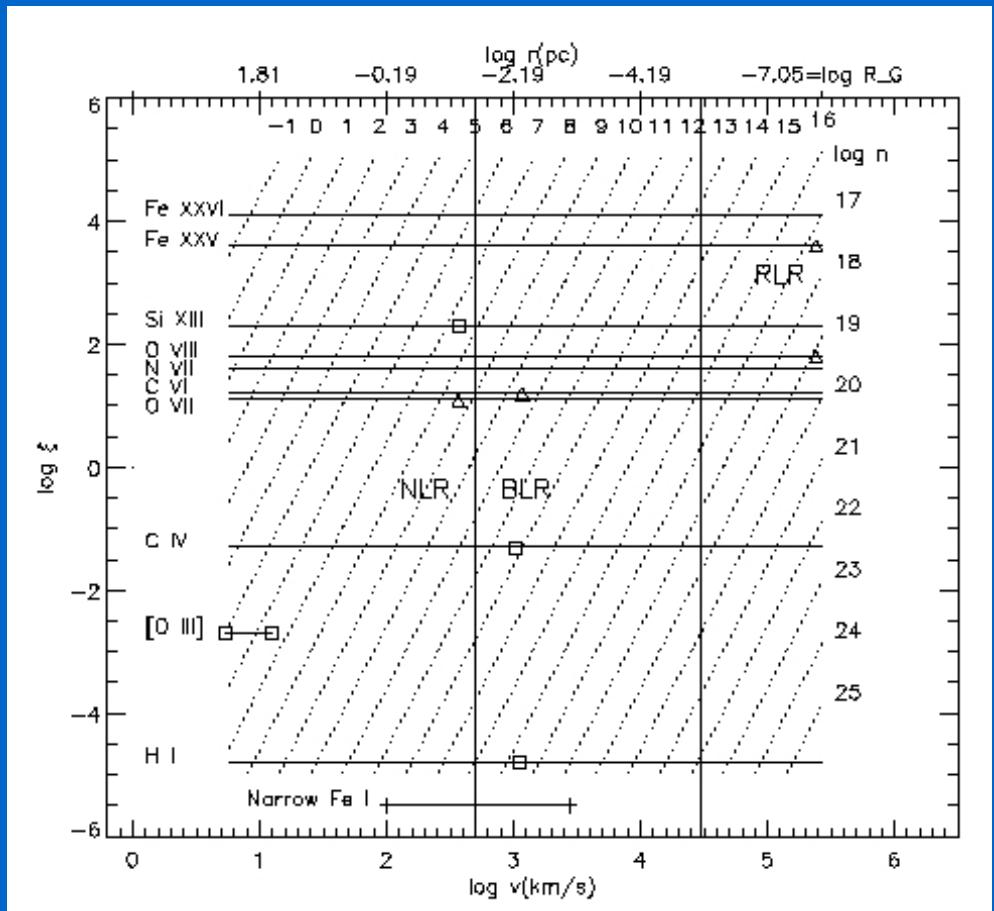
# Absorber Ionization Distribution

- ★ Strong trend of increasing column density with ionization parameter  $\xi = L/nr^2$ .
- Emitter and absorber have similar columns.
- See also: Steenbrugge et al. 2003, NGC 5548



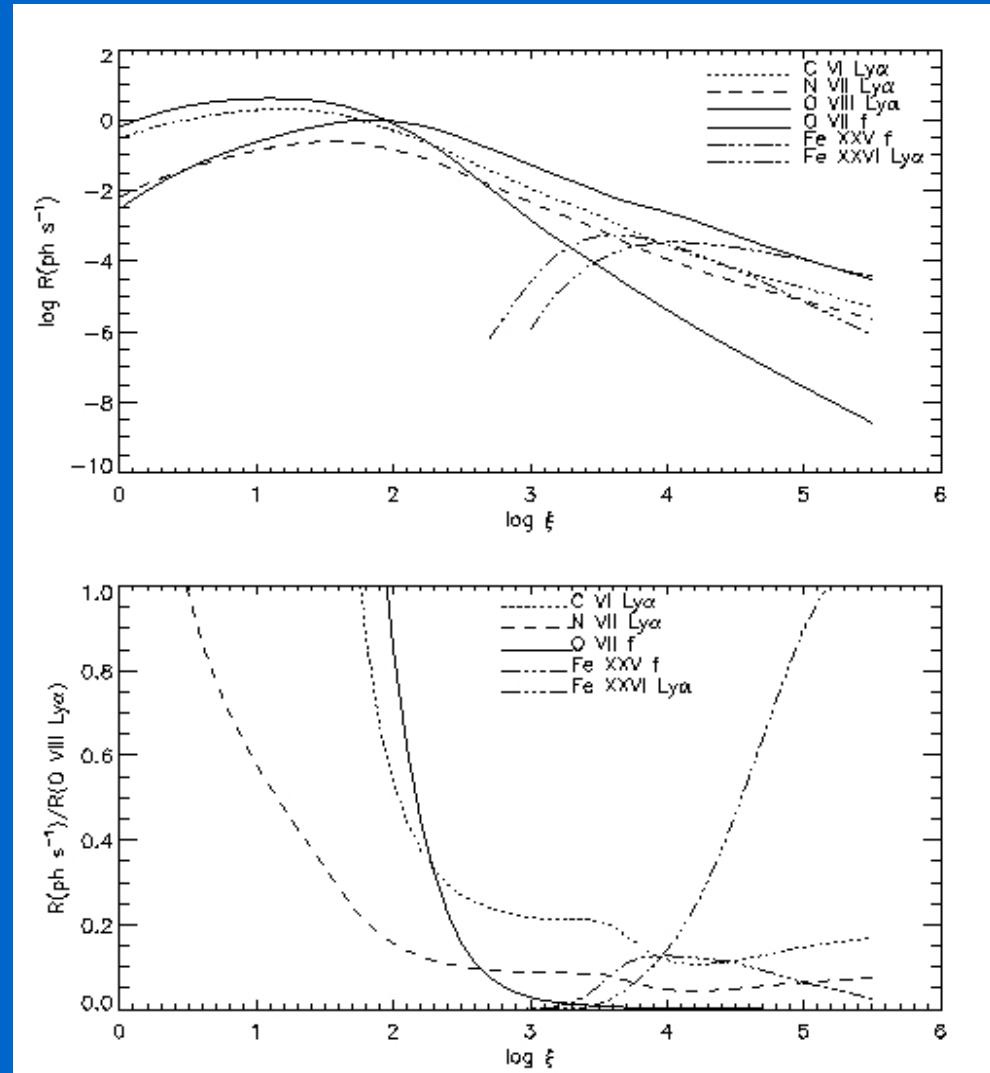
# Emission line regions: radial/ionization distribution

- ◆  $M_{BH} = 1.5 \times 10^9 M_{\text{sun}}$ ,  
Keplerian orbits.
- ★ NLR and BLR span  
enormous range of  
ionization parameter and  
density.
- ★ What causes the gap  
between RLR and BLR?



# RLR Ionization and Abundances

- Strong Fe XXV, no O VII imply high ionization parameter ( $\log \xi = 4.0$ ).
- ★ Strong O VIII but no N VII consistent with solar abundances.
- Bowen resonance? - Sako 2003.



# Summary

- Relativistic O VIII Ly $\alpha$  and higher order lines discovered in NGC 4051, respond to soft X-ray flux.
- Emission from photoionized disk at  $1.5 R_G$ , with solar abundances, (low optical depth)
- Ionized outflow with  $\log \xi = -1$  to 3, most mass in high ionization states.
- Broad C VI emission from BLR, large range in ionization parameter.
- *Relativistic soft X-ray lines are real, and diagnostic of accretion disk geometry and state.*